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2 Summary and main conclusions

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Bioenergy is energy of biological and renewable origin, normally derived from purpose-grown energy crops or by-products of agriculture, forestry or fisheries. Examples of bioenergy resources are fuel wood, bagasse, organic waste, biogas and bioethanol. Bioenergy is the only renewable energy source that is available in gaseous, liquid and solid forms.

Growing concern about the sustainability of energy supplies (especially in the transport sector), supply security and the need to take action on climate change have all served to increase interest in bioenergy. Technological advances in biomass conversion, combined with significant changes in energy markets, have stimulated this trend and led to the invention of a new term, "modern bioenergy", covering a number of traditional and emerging areas of technology. The world's government-funded energy-related R&D is decreasing, but bioenergy R&D has increased in both relative and absolute terms during the last decade or so.

Today bioenergy provides 11–14% of the world's energy supply, but there are significant differences between industrialised and developing countries. In many developing countries bioenergy is the most important energy source. The use of bioenergy in the industrialised countries, on the other hand, varies from 4% in the USA to 20% in Finland. Danish energy production from biomass in 2001 was approximately 42 PJ, or 5% of the country's total energy consumption of 829 PJ.

In principle, modern bioenergy could cover all the world's energy requirements, but its real technical and economic potential is much lower. The annual theoretical potential of bioenergy has recently been estimated at 2900 EJ, but the present practical technical and economic potential is estimated to be 270 EJ. Current use of bioenergy is estimated to be only around 55 EJ.

Supply systems – harvesting, collection, handling and storage – are a great technical challenge for modern bioenergy. Biomass is a local and bulky resource, so transport costs can be a barrier. This obstacle can be overcome by developing locally-applicable technologies to convert bulky raw materials into energy-dense solid, liquid or gaseous fuels.

Land for the production of bioenergy resources is another key issue, since competition for land could lead to reduced levels of food security. In many developing countries, however, food and fuel production can be integrated in complementary land-use systems. In industrialised countries, much of the land being removed from agricultural production, such as EU "set-aside", could be used to produce bioenergy.

The end products of bioenergy systems can be used for:
• transport;
• electricity supply; and
• heating.

In the transport sector, biodiesel produced from vegetable oils could play an important role. Further technical advances could also create "biolubricants" from vegetable oils. Another promising transport fuel is ethanol produced from plant materials by biological processes.

For electricity production, the use of bioenergy crops is an effective way to mitigate the greenhouse effect by reducing the use of fossil fuels. Using biomass for heat and power production increases the security of energy supply by lowering the demand for non-renewable fossil fuels. In the near future, solid oxide fuel cells (SOFCs) offer a promising route to efficient electricity production. For sustainable power, we should continue to develop gasification and fuel cell conversion systems based on biomass.

Conversion technologies need to be chosen to suit the energy service in question: heat, electricity or transport fuel. Thermochemical processes convert biomass into liquid or gaseous energy carriers that have higher energy densities and more predictable and convenient combustion characteristics than the raw materials from which they are made. Catalytic liquefaction can produce fuels of even higher quality and energy density.

Another conversion technology, the use of micro-organisms to produce ethanol, is an ancient art. These micro-organisms are now regarded as biochemical "factories" for converting organic waste into gaseous or liquid fuels.

Modern biotechnology could contribute to the development of CO_2-neutral power generation systems in two distinct ways. The first of these is traditional or "white" biotechnology, which in this context deals with the use of fermentation processes and enzymes in the downstream processes of biomass conversion. This area of technology is firmly established and forms an integral part of the fermentation processes described in this report.

The other area is "green" biotechnology, which uses genetic engineering to tailor the characteristics of biomass to optimise its performance as an energy resource. Such technology is still at the emerging stage and has so far been only superficially explored.

To date, almost the only biomass types to have been investigated as energy sources using green biotechnology have been those that are already available from traditional cropping or foresting systems. The challenge is now to establish small-scale prediction systems that will allow the establishment of structure-function relationships between the composition of biomass and its convertibility in energy conversion systems. This will allow us to explore and create biodiversity in energy crops, as well as improving the performance of bioenergy systems. Many "top ten" lists of emerging generic technologies include modern biomass-based energy systems. However, many bioenergy technologies are still wide open for development. The future of bioenergy depends strongly on the interactions between specific emerging energy technologies and more generic developments in biotechnology and information technology.

Key messages

The most important driving forces for modern bioenergy are:

- security of supply, based on to the use of domestic resources;
- local employment and local competitiveness;
- local, regional and global environmental concerns; and
- land use aspects in both developing and industrialised countries.

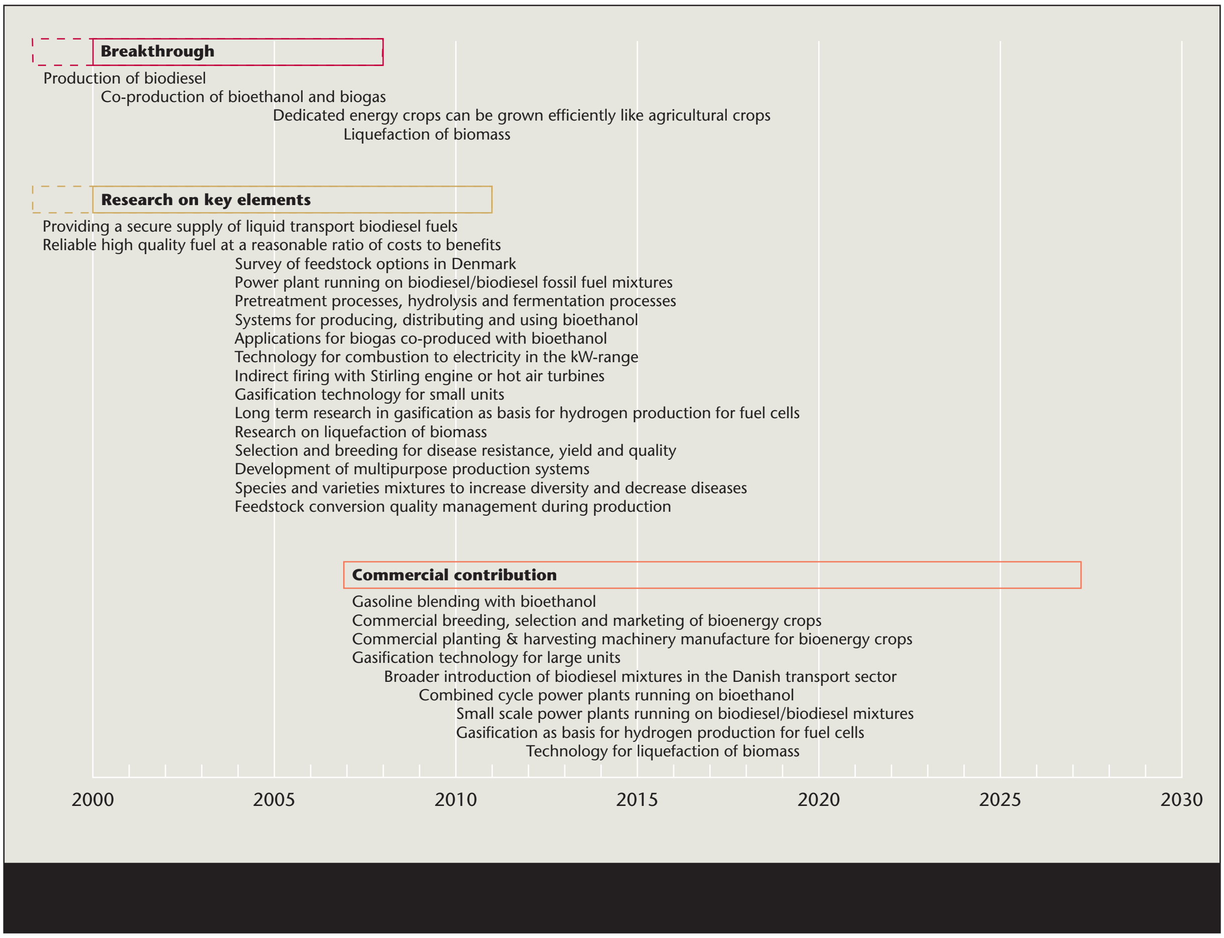
Barriers are:

- the competitiveness of the various bioenergy technologies varies from close to competitive to far from;
- the competitiveness is strongly depending on e.g. the amount of externalities included in the cost calculations;
- in general bioenergy technologies need to be moved down the learning curve;
- resource potentials and distributions;
- costs of bioenergy technologies and resources;
- lack of social and organisational structures for the supply of biofuels;
- local land-use and environmental aspects in the developing countries; and
- administrative and legislative bottlenecks.

These barriers can be lowered through dedicated interventions by both public and private sector entities, focusing on:

- development and deployment of more cost-effective conversion technologies, especially those that yield end-products – solid or liquid – with high energy densities;

Figure 1. Time scale from break through to commercial contribution



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- development and implementation of improved, dedicated, bioenergy crop production systems;
- establishment of bioenergy markets and organisational structures for transporting and delivering bioenergy resources and products; and
- valuation of the environmental benefits for society e.g. on carbon balance.

Our conclusions are:

- simply burning biomass in power plants remains a limited market in industrialised countries;
- in developing countries there is still room for efficiency improvements in biomass burners;
- there is a great potential in upgrading biomass into fuels that can be used in more traditional end use technologies;
- there is a need to develop new harvesting and conversion technologies for energy crops;
- the combination of biofuels with fuel cells could considerably reduce CO_2 emissions in the transport sector; and
- agriculture has taken thousands of years to develop plants that are especially suitable for food. There is immense potential in developing plants that are especially suitable as sources of energy.

Our recommendations are:

- modern bioenergy has large potential, both globally and for Denmark, but more R&D is needed;
- Denmark has a long tradition of agriculture, highly-qualified farmers and a leading industrial position in biotechnology, pharmacy, plant breeding, seed production, energy technologies and renewable energy. Together, these factors give Denmark the opportunity to become the first mover on most key issues in modern bioenergy;
- to exploit these advantages, we deem it of utmost importance that Danish research institutions establish cross-institutional research platforms and co-operative interdisciplinary projects. Such projects should include as stakeholders politicians, industrialists and venture capitalists. In particular, politicians must contribute by setting out the way for bioenergy, and supporting the transition from basic research to competitive technologies ready to enter the market.